THE PENNSYLVANIA STATE UNIVERSITY

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IONOSPHERIC RESEARCH

Scientific Report No. 213

A STUDY OF THE IONOSPHERE AT MID LATITUDES, BASED ON TOTAL ELECTRON CONTENT

by

Francis H. Hibberd

July 10, 1964

IONOSPHERE RESEARCH LABORATORY

University Park, Pennsylvania

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ABSTRACT

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This report describes a study of the total electron content of the ionosphere, derived from satellite Doppler measurements, for the period July 1961 through June 1962. By combining the electron content with simultaneous values of the maximum electron density and true height data obtained from a nearby ionosonde, scale heights and temperatures have been obtained. The variations of the electron content and other ionospheric parameters with time of day, season, solar radio flux and magnetic disturbance are investigated.

AUTHOR

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1. INTRODUCTION

A study has been made of total electron content data for the ionosphere for a middle latitude station over the period July 1961 through June 1962. The data consist of a series of about two measurements per day, on the average, extending over almost all of this period, and were derived from Doppler measurements on radio signals received from the satellite Transit 4A.

In addition to the electron content, electron-density true height data from the ground up to the height of maximum ionization were available from a nearby ionosonde. By combining simultaneous electron content and true height data it has been possible to obtain information concerning the scale height and temperature in the upper part of the ionosphere.

2. NATURE OF THE DATA

The electron content data were derived from dispersive Doppler measurements on signals from Transit 4A at harmonic frequencies of 54 Mc/s and 324 Mc/s using a method similar to that described by Ross.[1] The Doppler measurements and their reduction to electron content were made by Dr. Ross and his colleagues.

The electron content data used in the present study have been selected from the total bulk of data by a careful examination of the individual Doppler records. Only those Doppler curves that were essentially complete, were free of major fluctuations, and were reasonably symmetrical about the time of occurrence of minimum satellite zenith angle (and thus free from obvious effects of horizontal gradients of ionization) have been used. Further, the data were restricted to those obtained when the minimum longitudinal distance between satellite and observing point was less than 15 degrees, corresponding to a central angular distance between the sub-ionospheric point and the observing point not greater than about 4 degrees. The accuracy of the values of electron content is considered to be generally about 5-10 per cent. For the whole of the period the altitude of the satellite was between 880 and 1000 km. so that the satellite was above virtually all of the ionization in the ionosphere. Fewer results are available for the nighttime because phase fluctuations resulting from the passing of the rays through ionospheric irregularities, which seriously distort the Doppler curves, appear to be more common at night.

The electron content measurements were made at State College, 40. 8 N, 77. 9 W. The corresponding values of maximum electron density and other ionogram data were obtained from ionograms for Washington, 38. 7 N, 77. 1 W.

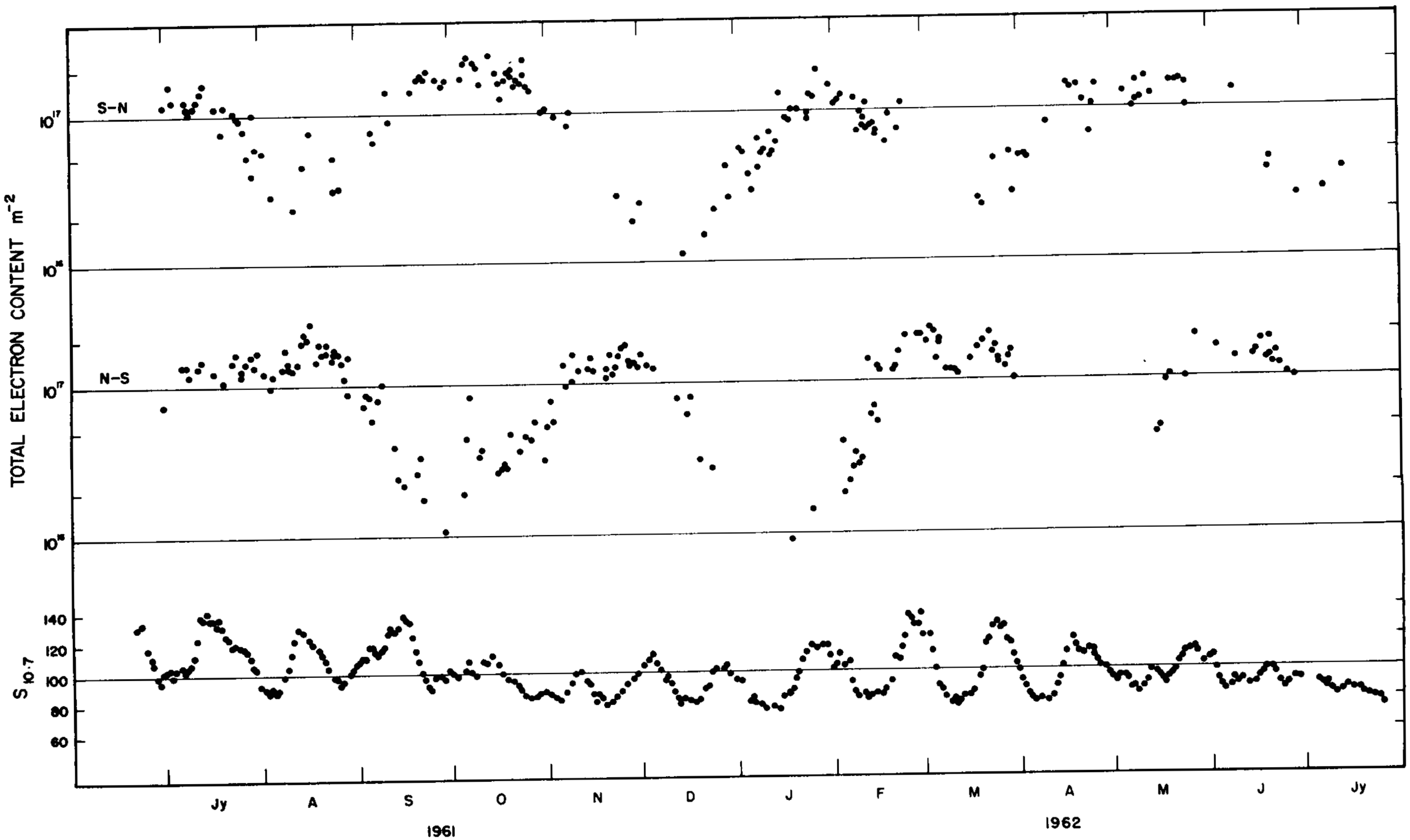
Because of the relative motion of the satellite and earth, one measurement of electron content per day, on the average, is obtained when the satellite passes near the observing station travelling in a northward direction and another measurement is obtained about half a day later when the satellite is again near the station and is travelling southward. As a consequence of the precession of the satellite orbit the times of passage recede on the average from day to day so as to sweep through a 24 hour period in about three months.

Values of electron content obtained when the magnetic planetary index K_p was greater than 4+ in the preceding 24 hours (in some instances, 48 hours) have been separated from the main data. The effects of magnetic disturbance are examined separately.

3. DIURNAL VARIATION OF ELECTRON CONTENT

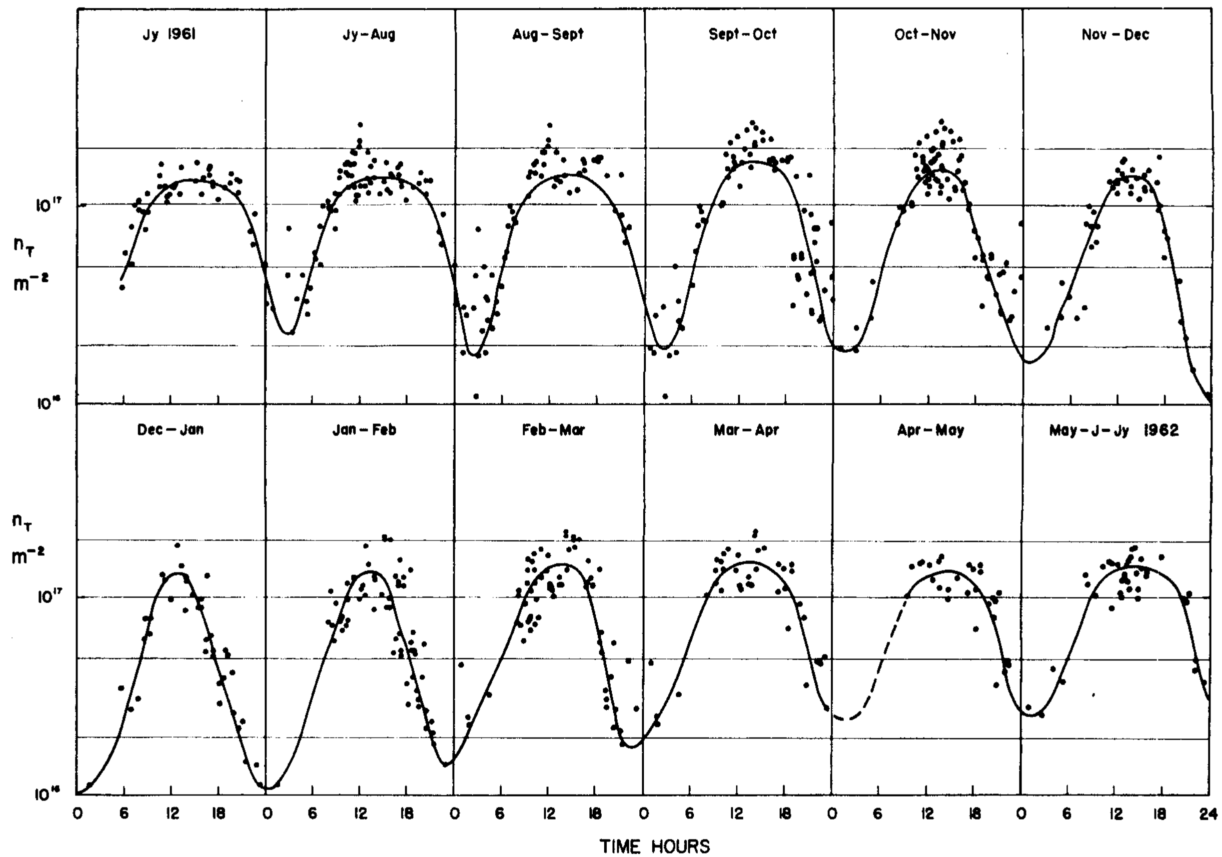
The total electron content, n_T, under magnetically quiet conditions is plotted against the date in Figure 1, with the north-going (S-N) and south-going (N-S) passages shown separately. Because the time of day of each observation recedes as the date advances, the diurnal variation of electron content may be seen, with the maxima corresponding to daytime and the minima to night with the time of day advancing from right to left. The bottom curve in Figure 1 shows the 10.7 cm solar radio flux S. There are indications of a correlation between the 27-day variation of solar flux and the daytime electron content, particularly in February-March 1962. This is examined in the next section.

The time of observation of each point in Figure 1 does not change in a completely uniform manner with the increase in date. For this reason the data are presented differently in Figure 2 to show the diurnal and seasonal behavior. Here the values of electron content for both directions of travel have been grouped together for pairs of adjacent months and plotted against hour of day. The diurnal variation is more clearly seen, with a change by a factor of about 10 from daytime maximum to nighttime minimum. The maximum value of n_T occurs 3 hours later than noon in mid-summer and 1 hour later than noon in mid-winter.



TOTAL ELECTRON CONTENT FOR QUIET DAYS

FIGURE I



DIURNAL VARIATION OF TOTAL ELECTRON CONTENT

FIGURE 2

4. VARIATION OF MIDDAY ELECTRON CONTENT WITH SOLAR FLUX

Figure 1 suggests that the total electron content is correlated with the intensity of the 10.7 cm solar radio flux. This has been investigated further by plotting for various months the values of n_T during the middle of the day, when the diurnal rate of change of n_T is small, against the daily values of the solar flux S, in units of 10^{-22} watts/m^2/cycle/sec. The results are shown in Figures 3, 4, and 5, and a linear relation between n_T and S is seen. In February-March 1962 (Figure 5), when the nearly stationary midday period is of short duration, it is possible to see that the morning and afternoon values of n_T at a given hour are lower than those near midday but have about the same rate of change with S as the midday values. The few January 1962 afternoon values, not shown, are in general agreement with those in Figure 5.

If we write

$$n_T = n_{T,100} + \frac{\partial n_T}{\partial S}(S-100)$$

we obtain from Figures 3, 4, and 5 the following values, to a precision of about 10%,

	$n_{T,100}$	$\partial n_T/\partial S$	$\frac{1}{n_T}\partial n_T/\partial S$	Range of S
Mean winter	1.85×10^{17}	0.038×10^{17}	0.021	80-115
Mean summer	1.45×10^{17}	0.028×10^{17}	0.019	80-125

Taylor[2] has collected a number of published measurements of electron content and combined them with his own data to show the

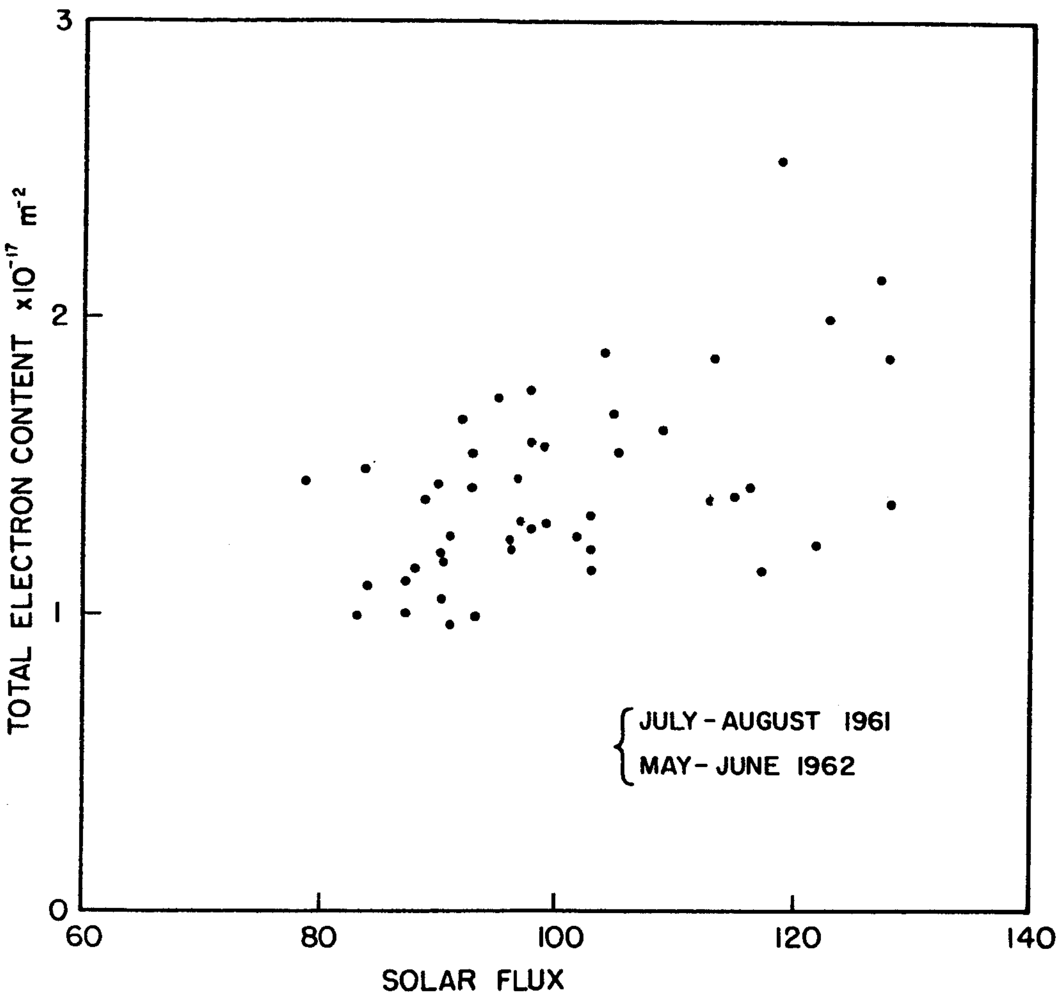


FIGURE 3

VARIATION OF MIDDAY ELECTRON CONTENT WITH SOLAR FLUX - SUMMER

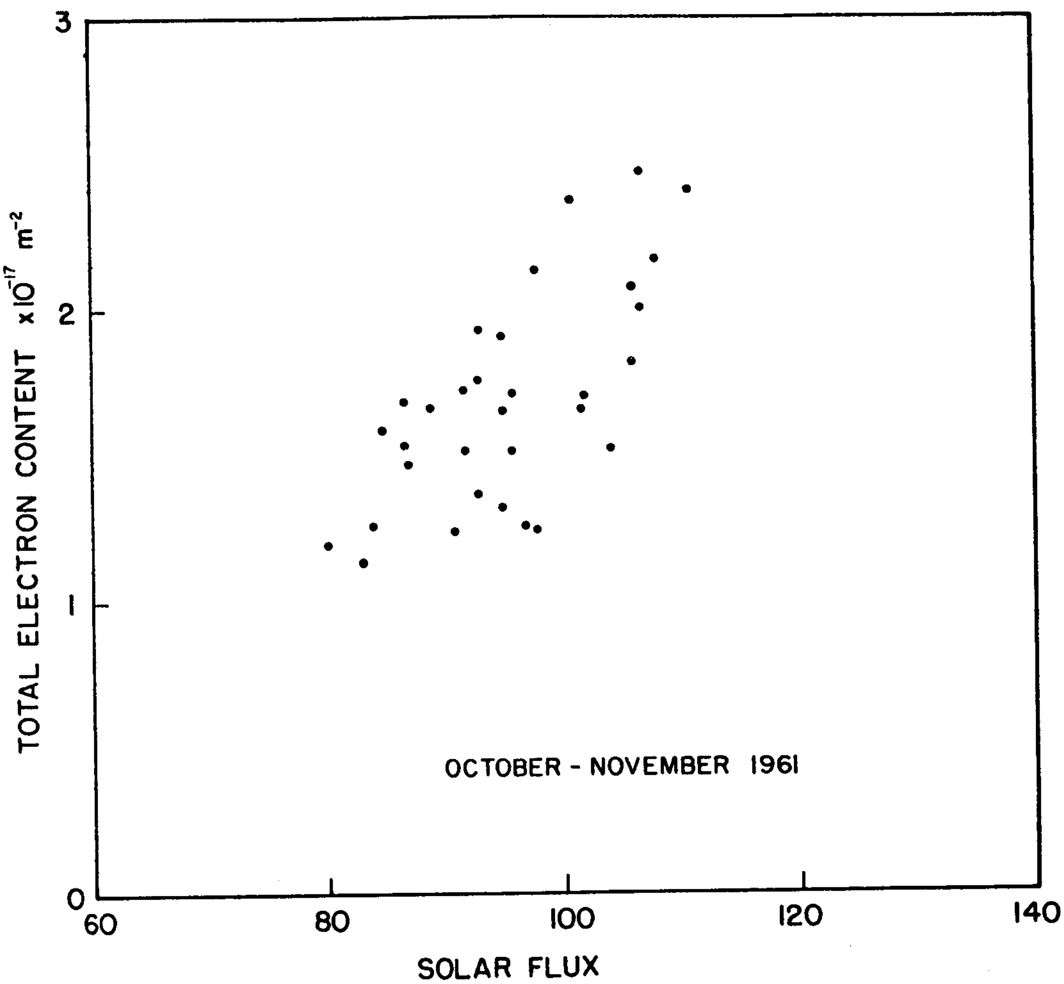


FIGURE 4
VARIATION OF MIDDAY ELECTRON CONTENT WITH SOLAR FLUX — OCTOBER-NOVEMBER 1961

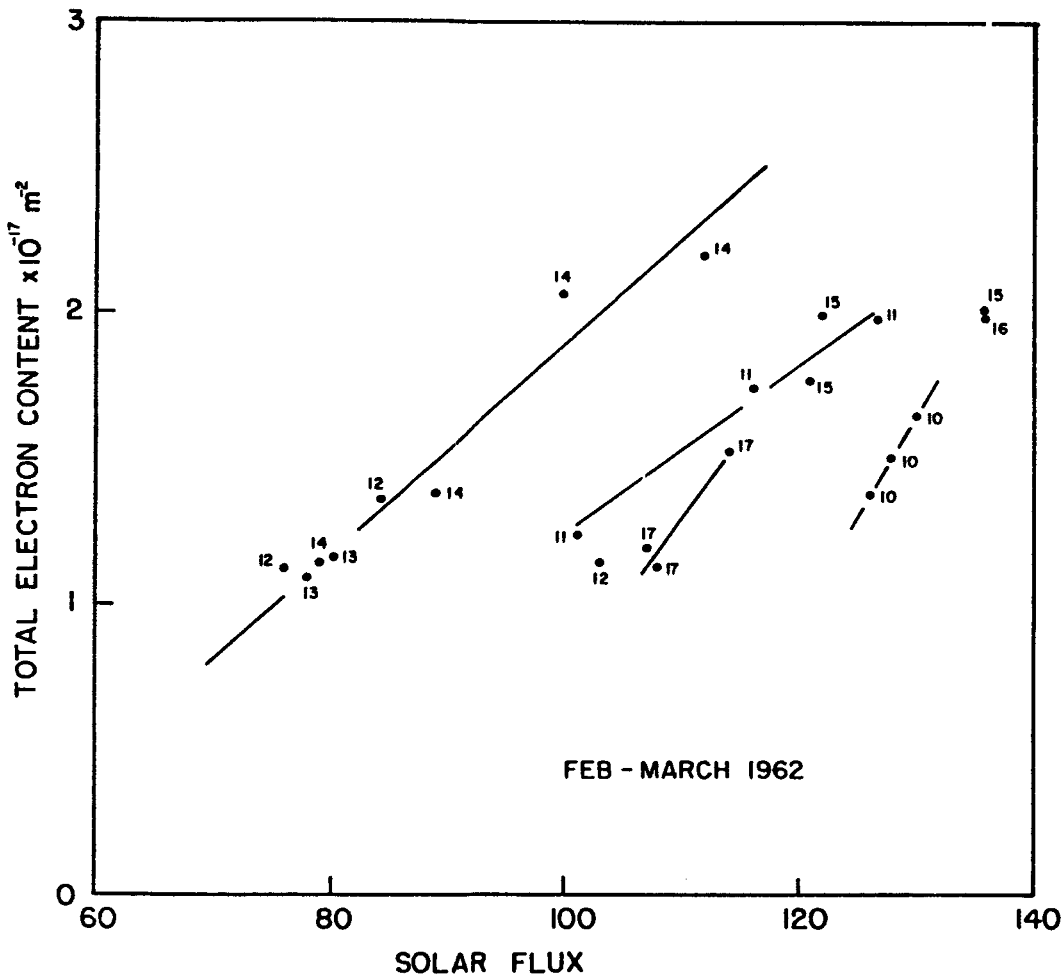


FIGURE 5

VARIATION OF ELECTRON CONTENT WITH SOLAR FLUX FOR SEVERAL DAYTIME HOURS

FEBRUARY— MARCH 1962

relation between electron content and solar flux. Most of these measurements refer to higher values of S than the present data, and it is of interest to compare them. Taylor's measurements, those of other workers, and the results from the present study are shown in Figures 6 and 7 for winter and summer respectively. The mean values from the present study of n_T and the slope $\partial n_T/\partial S$, at $S = 100$, are also shown in Figures 6 and 7. A linear relation over the range of S from 80 to 250 in winter is clearly seen by Figure 6. There is more scatter in the summer date in Figure 7, but a linear relation appears to hold there also.

Some recent measurements by Titheridge[9] in the southern hemisphere are in very good agreement with the northern hemisphere results in Figures 6 and 7. Titheridge obtained in the southern winter of 1960 $n_T = 4.0 \times 10^{17}$ for $S = 166$, in the winter of 1961 $n_T = 2.5 \times 10^{17}$ for $S = 107$, and in the summer of 1960-61 $n_T = 2.8 \times 10^{17}$ for $S = 121$.

From Figure 6 the relation between n_T and S in winter is found to be in winter

$$n_T = \left(1.80 + 0.041\ (S-100)\right) \times 10^{17}\ \mathrm{m}^{-2} \quad \text{for } 80 < S < 250 \qquad (1)$$

From Figure 7 the relation in summer is, approximately,

$$n_T \approx \left(1.6 + 0.02\ (S-100)\right) \times 10^{17}\ \mathrm{m}^{-2} \quad \text{for } 90 < S < 220 \qquad (2)$$

Relation (1) is considerably more accurate than relation (2). However, there is no doubt that $\partial n_T/\partial S$ is considerably lower in

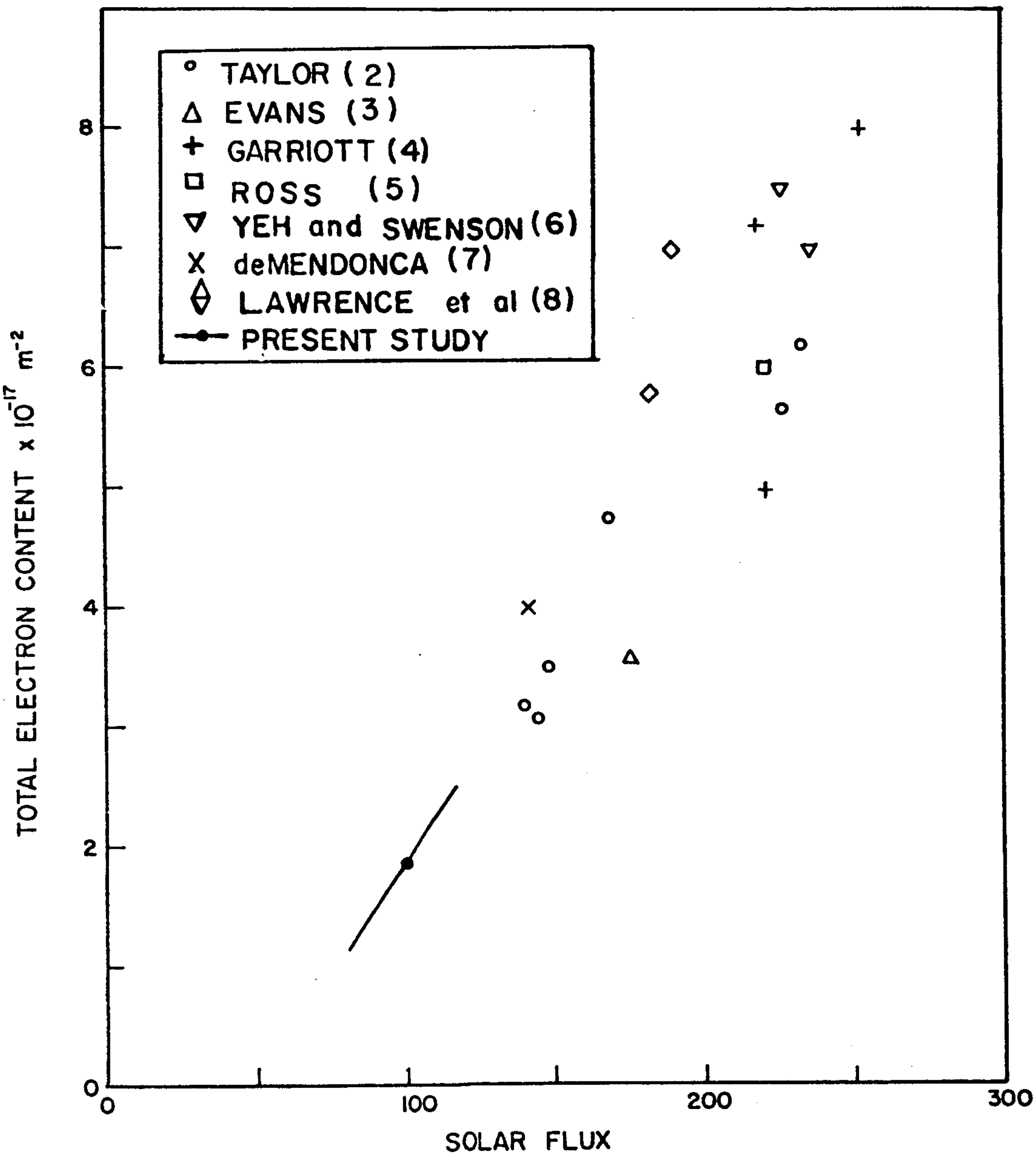


FIGURE 6

VARIATION OF ELECTRON CONTENT WITH SOLAR FLUX IN MIDDLE LATITUDES— WINTER (AFTER TAYLOR)

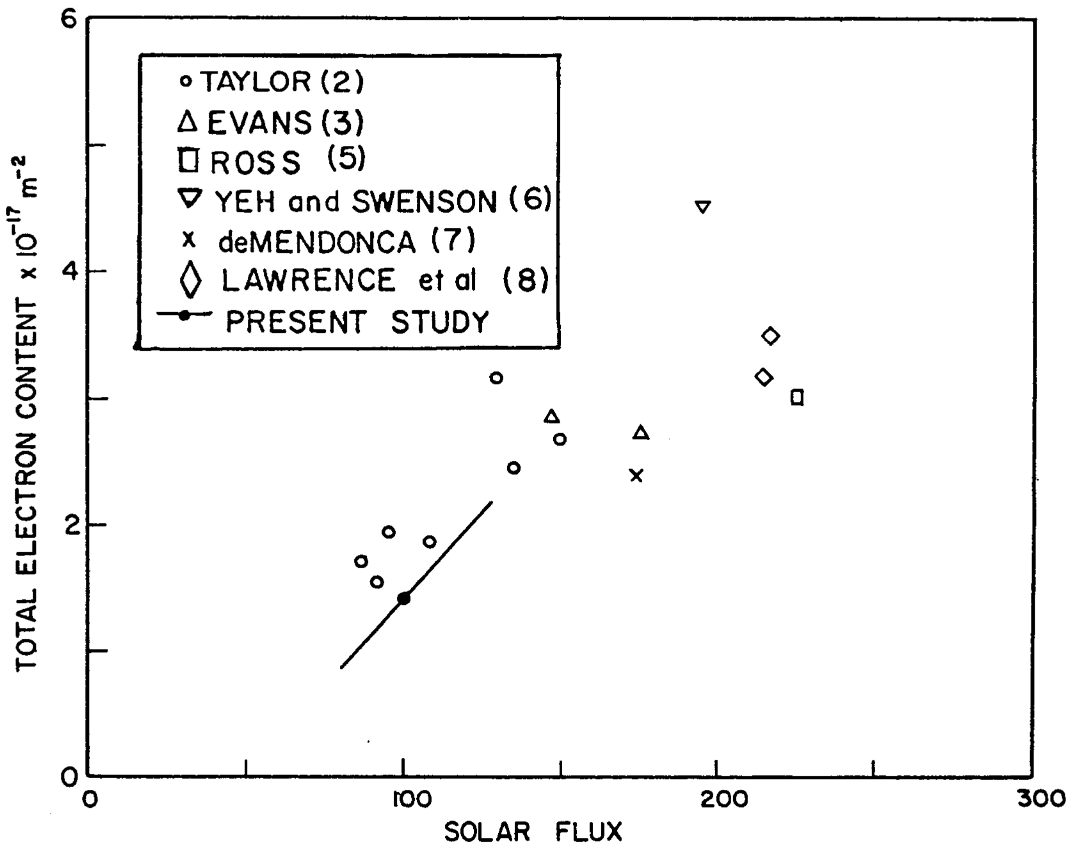


FIGURE 7

VARIATION OF ELECTON CONTENT WITH SOLAR FLUX IN MIDDLE LATITUDES — SUMMER

summer than in winter, although the logarithmic gradient, $\frac{1}{n_T} \partial n_T/\partial S$, is more nearly the same for both seasons and has the value of about 2% for S unit about S = 100.

It is of considerable interest to note that, at times of high solar activity, in middle latitudes, the midday value of total electron content is much greater in winter than summer, whereas at times of low solar activity the values in winter are only slightly higher than in summer. A similar effect is well known in the behavior of the maximum electron density N_m of the F_2 layer.

5. SOME LARGE ELECTRON CONTENTS AT NIGHT

In Figure 1, and also in Figure 2, it is seen that on a number of occasions the nighttime electron content is unusually large. Where the data are available, it is found that the electron content in the immediately preceding daytime period is also somewhat larger than the values on adjacent days. This is true for the nighttime S-N values on April 14, 16, February 22, March 18, 23, 28 and for N-S values on October 5, 6, 9, 11, 19. These dates mostly lie near maxima in S and the high nighttime value is evidently a consequence of the preceding high daytime value.

6. RATE OF LOSS OF ELECTRONS AT NIGHT

The nighttime portions of the log n_T-time curves in Figure 2 are almost linear. The slope is approximately the same for all months and is such that the time for the total electron content to fall by a factor of 10 is 7 ± 1 hours.

Under nighttime conditions there is no production of electrons and the rate of change of electron density at a given height is determined by

$$\frac{\partial N}{\partial t} = - \beta N - \mathrm{div}\,(N\underline{v})$$

where β is the effective attachment coefficient and $\underline{v}$ is the velocity of transport of electrons out of the region under consideration. When this equation is integrated over all heights from o to ∞ - that is, over the surface of an infinite vertical cylinder of unit cross section - we obtain for the rate of change of the total electron content in the column

$$\frac{\partial}{\partial t} \int_o^{\infty} N\,dh = - \int_o^{\infty} \beta N\,dh \qquad (3)$$

provided that the velocity of transport is entirely vertical.

The attachment coefficient β is known to decrease fairly rapidly with height in the F region so the product βN will possess a maximum somewhere below the height h_m of the maximum electron density N_{max}. The main contribution to the integral on the right hand side of (3) will come from this region, where βN is large. If we denote by $\overline{\beta}$, the average value of β in the vicinity of the maximum in βN we may write, approximately,

$$\int_o^{\infty} \beta N\,dh \approx \overline{\beta} \int_o^{\infty} N\,dh = \overline{\beta}\, n_T$$

Equation (3) then becomes, approximately,

$$\frac{\partial n_T}{\partial t} \approx -\overline{\beta} \quad n_T$$

and its solution is

$$n_T(t) = n_{T_{t=0}} \quad e^{-\overline{\beta} t}$$

The observed decay of n_T then yields

$$\overline{\beta} \approx (0.9 \pm 0.1) \times 10^{-4} \text{ sec}^{-1} \quad .$$

7. RATE OF ELECTRON PRODUCTION AND HEAT INPUT

The rate of change of electron density at a given height is, in general, given by

$$\frac{\partial N}{\partial t} = q - \beta N - \operatorname{div}(N\underline{v})$$

where q is the number of electrons produced per unit volume per second.

For a vertical column of ionization, when the drift is vertical, this yields

$$\frac{\partial}{\partial t} \int_o^\infty N \, dh = \int_o^\infty q \, dh - \int_o^\infty \beta N \, dh$$

Near midday, when $\frac{\partial}{\partial t} \int_o^\infty N \, dh = 0$, we have

$$\int_o^\infty q \, dh = \int_o^\infty \beta \quad N \, dh$$

$$\approx \quad \bar{\beta} \int_{0}^{\infty} N \, dh$$

The nighttime value of $\bar{\beta}$ has been found to be $0.9 \times 10^{-4} \sec^{-1}$. The midday value of $\int N \, dh$ is approximately $1.5 \times 10^{17} \; m^{-2}$. Combining these we find that the daytime rate of total production of electron is

$$\int_{0}^{\infty} q \, dh \approx 1.4 \times 10^{13} \text{ electrons } m^{-2} \sec^{-1}$$

This value is almost certainly too low, because we have neglected the diurnal change of $\bar{\beta}$. $\bar{\beta}$ will be considerably larger in the daytime than at night because h_m is lower in the daytime and because the concentration of the molecular species taking part in the loss process is greater at a given height by day. Loss by recombination like processes in the lower part of the ionosphere is also neglected.

A lower limit to the heat input flux associated with the ionizing radiation may be estimated from the ionization rate, taking the ionization potential of atomic oxygen as 13.6 volts, or an energy of 2.1×10^{-11} ergs, and is

$$\text{Heat input flux at midday} \sim 0.03 \text{ ergs cm}^{-2} \sec^{-1}$$

8. <u>SCALE HEIGHT AND TEMPERATURE</u>

The scale height and temperature of the ionosphere are related to the N(h) profile and vertical extent of the ionization. The simplest measure of the vertical extent is the equivalent slab thickness τ, defined as

$$\text{Thickness, } \tau = \frac{\text{Total electron content } n_T}{\text{Maximum electron density, } N_m}$$

Wright (1960) has shown that when the profile has the Chapman form

$$N = N_m \exp \frac{1}{2} (1 - z - e^{-z}) \tag{4}$$

where z is the normalized height measured from the height h_m of maximum electron density, in units of the scale height H, viz

$$z = (h - h_m)/H$$

the following relations hold:

$$n_T = 4.13 \text{ H } N_m \tag{5}$$

$$n_a = 2.82 \text{ H } N_m \tag{6}$$

$$n_b = 1.31 \text{ H } N_m$$

$$n_a/n_b = 2.15$$

Here n_a and n_b are the integrated electron contents above and below h_m respectively.

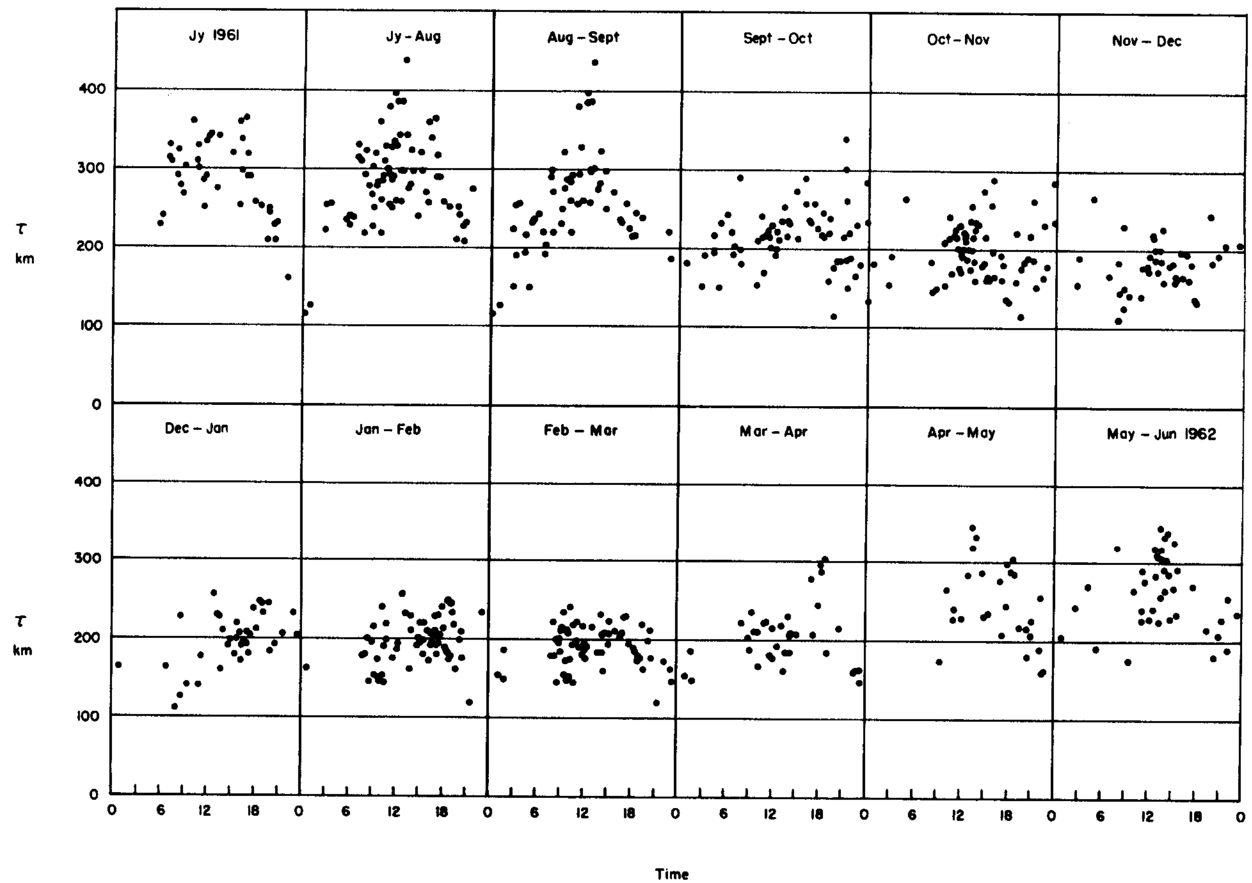
It is well known that an ionosphere controlled by diffusion of the electrons and ions, with a height dependent effective attachment process for electron loss, and with uniform vertical drift, will rapidly assume the form described by Equation (4). In the above expressions the scale height H is that of the ionizable constituent, generally considered to be neutral atomic oxygen.

In order to examine the diurnal and seasonal behavior of the thickness τ , the values of n_T in Figure 2 have been divided by the corresponding values of N_m and plotted in Figure 8. A diurnal variation in τ with a midday maximum appears to be present in summer but no clear variation is discernible in winter. At least part of the large scatter arises because τ contains the experimental errors in both n_T and N_m.

For a Chapman distribution τ is directly proportional to the scale height H, and therefore to the temperature. The summer diurnal variation in τ may correspond in part to a temperature variation. However, because of the large scatter, the only definite conclusion that can be drawn from Figure 8 is that in 1961-62 the daytime thickness was approximately 300 km in summer and 200 km in winter.

It is of interest to compare the midday thickness in September 1961 with measurements made for earlier years by Ross and Anderson[11]. The results for 1961 are shown in Figure 9, together with those for preceding years. It is noticed that the decrease in τ with decreasing solar flux and sunspot number that was found by Ross and Anderson continues into 1961.

The scale height deduced from the equivalent thickness τ of the whole ionosphere, using equation (4) based on a Chapman distribution, will contain some error because the distribution of ionization below h_m, especially in the daytime, departs somewhat from the Chapman form. It is preferable to examine the ionization above h_m, where the distribution is much closer to the Chapman form, and



DIURNAL AND SEASONAL VARIATION OF EQUIVALENT THICKNESS τ

FIGURE 8

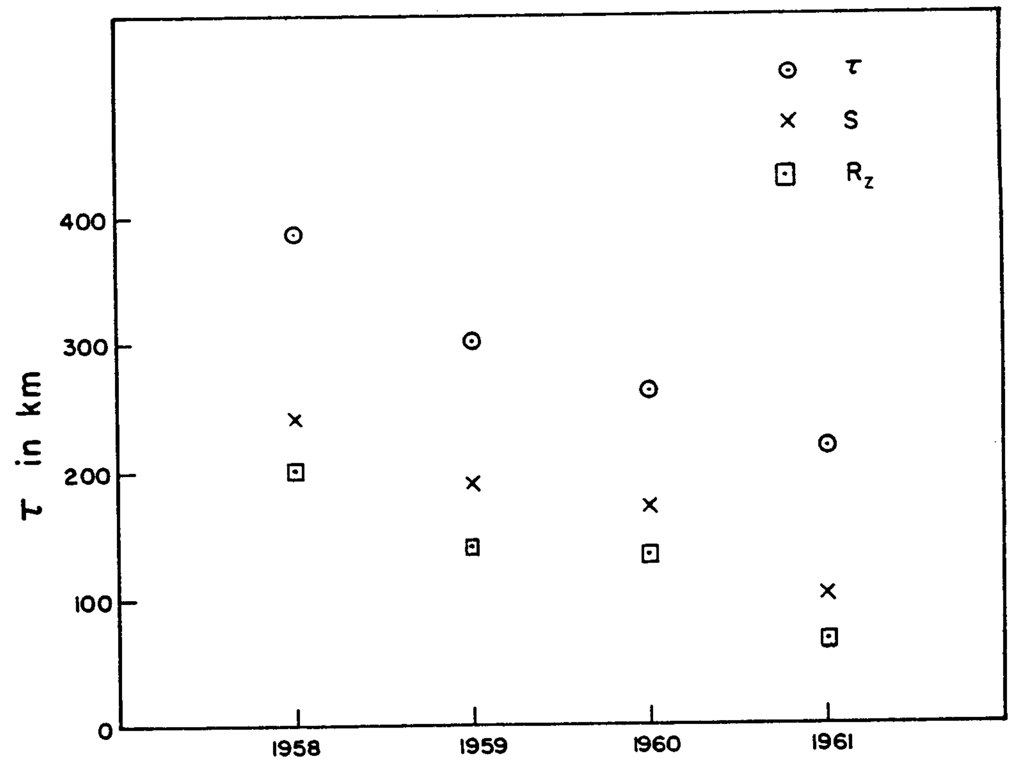


FIGURE 9

VARIATION OF SEPTEMBER MIDDAY EQUIVALENT THICKNESS τ WITH THE SOLAR CYCLE

[AFTER ROSS and ANDERSON (11)]

deduce the scale height and temperature in this region. The electron contents n_b below the maximum, obtained from ionograms, have been subtracted from the total contents n_T to give the contents n_a above the maximum. The scale height H_a in this region is then given by

$$H_a = \frac{n_a}{2.82\ N_m}$$

The temperature T_a is given by

$$H_a = \frac{k\ T_a}{m\ g}$$

m has been taken as the mass of atomic oxygen and g has been taken as 9.0 meters sec^{-2}, corresponding to an altitude of 280 km.

The individual values of H_a and T_a obtained had a fairly large scatter. Because of this and the relatively small amount of data it was not possible to see whether there was any diurnal or seasonal variation, or correlation with solar flux. The values for the middle daylight hours were averaged over each month. They are listed in Table 1, together with results for the other "nighttime" hours.

The number of data in Table 1 is not as large as in Figure 8 because there are not as many good records of both n_T and n_b as there are of n_T alone. Also, ionosonde data for August-November 1961 are not yet available.

The nighttime values of scale height do not differ significantly from the daytime values but it must be noted that there are not many measurements for the early morning included in the nighttime results in Table 1. Further, the measured contents n_b do not include

TABLE 1

	Av.	Day				Night			
	S	hours	No. of obs.	H_a	T_a	hours	No. of obs.	H_a	T_a
July 1961	113	1100-1800	16	69	1200	1900-1000	13	69	1200
Dec. '61-Jan. '62	110	1200-1500	5	48	830	1600-1100	11	51	880
Feb. 1962	124	1200-1500	3	41	710	1600-1100	26	44	760
March 1962	91	1200-1600	10	41	710	1700-1100	11	44	760
April 1962	-	1200-1700	0	-	-	1800-1100	8	66	1150
May 1962	94	1100-1800	6	53	920	1900-1000	6	51	880
June 1962	94	1100-1800	11	61	1050	1900-1000	4	58	1000

ionization near the bottom of the ionosphere with density too low to be detected by the ionosonde. Neglect of this is more serious at night than in the day and its inclusion would lead to somewhat lower values of H_a at night.

The average daytime scale height is greater in summer than in winter. The daytime temperatures for July 1961 and June 1962 and the difference between them are very close to the thermopause temperatures estimated by Nicolet (1963) for these months.

9. RATIO OF ELECTRON CONTENTS ABOVE AND BELOW h_m

A useful measure of the electron distribution in the ionosphere is the ratio of the electron content n_a above the height of N_m to the content n_b below this height. Results for summer, winter and spring months are shown in Figures 10, 11, and 12. The circled points in Figure 10 and 11 refer to magnetically disturbed conditions and are discussed later. All the other points were obtained during magnetically quiet conditions.

If the ionosphere were isothermal and the electron distribution had the Chapman form throughout, the ratio n_a/n_b would be equal to 2.15. A diurnal variation of n_a/n_b is seen in the figures. The low daytime values undoubtedly arise from the presence of the E and F_1 region ionization which gives a higher value to n_b than would be expected with a Chapman distribution.

10. EFFECTS DURING MAGNETIC STORMS

Before examining the data obtained during magnetic disturbances,

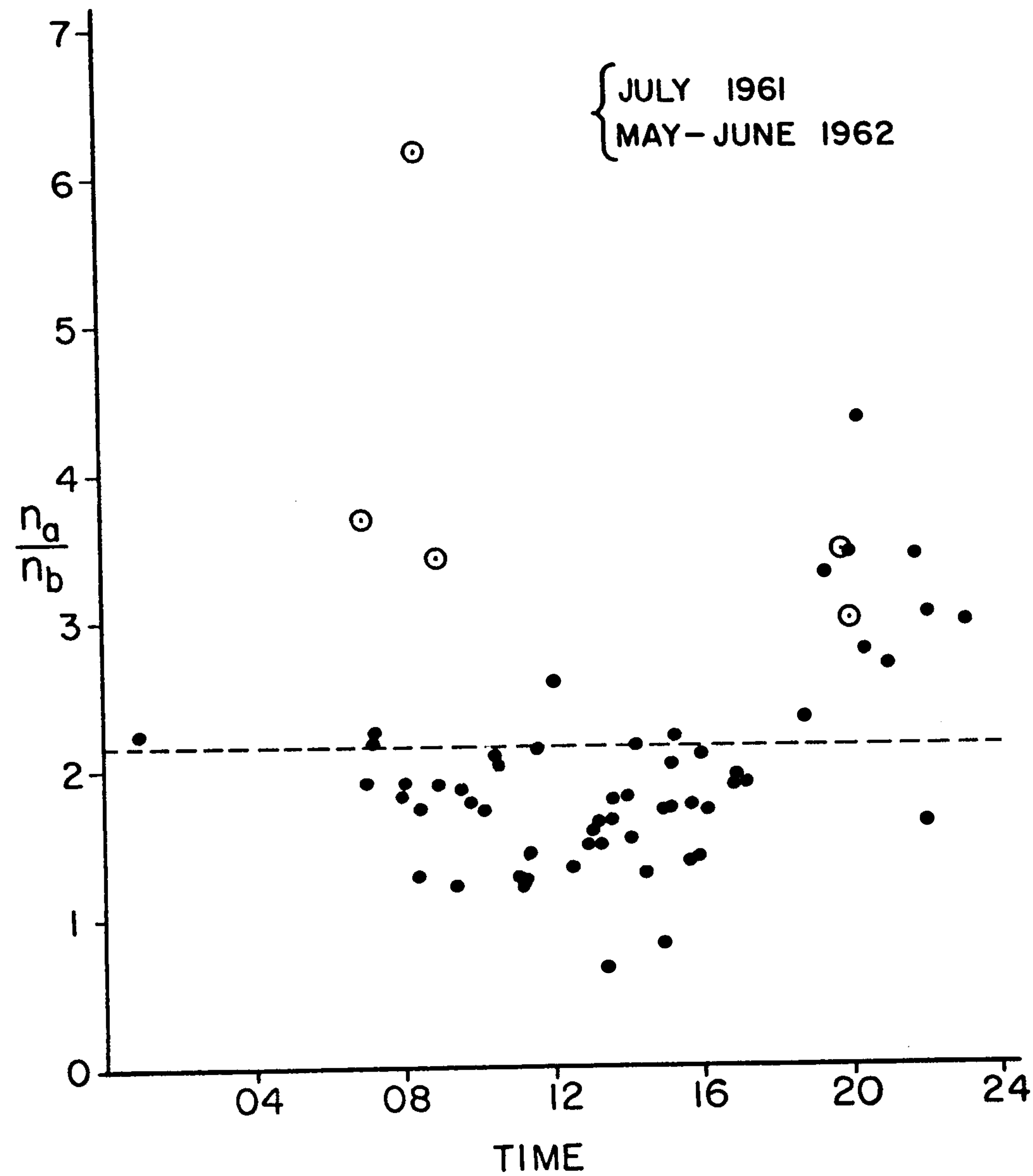


FIGURE 10

DIURNAL VARIATION OF THE RATIO $\frac{n_a}{n_b}$ DURING SUMMER MONTHS

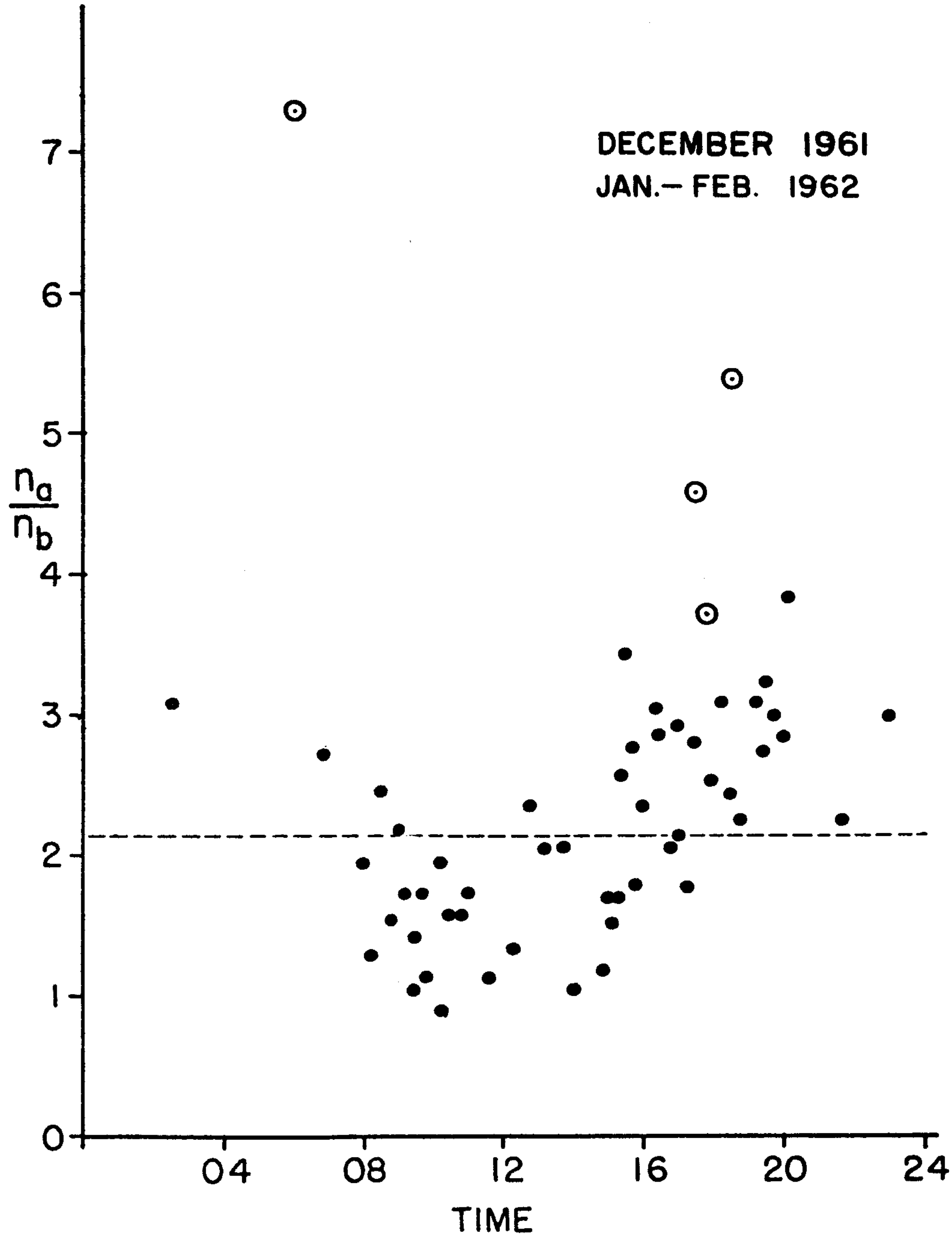


FIGURE 11

DIURNAL VARIATION OF THE RATIO $\frac{n_a}{n_b}$ DURING WINTER MONTHS

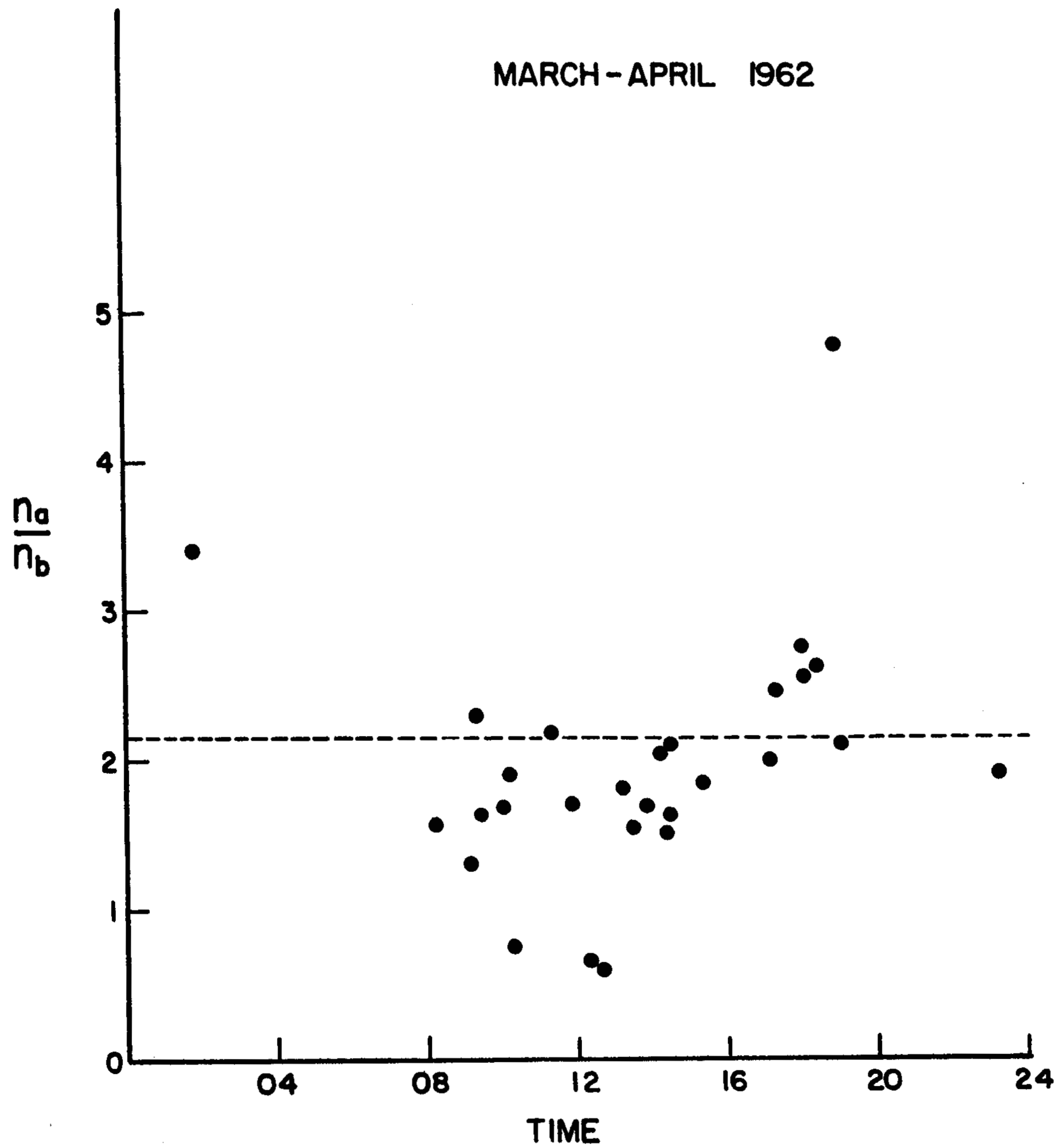
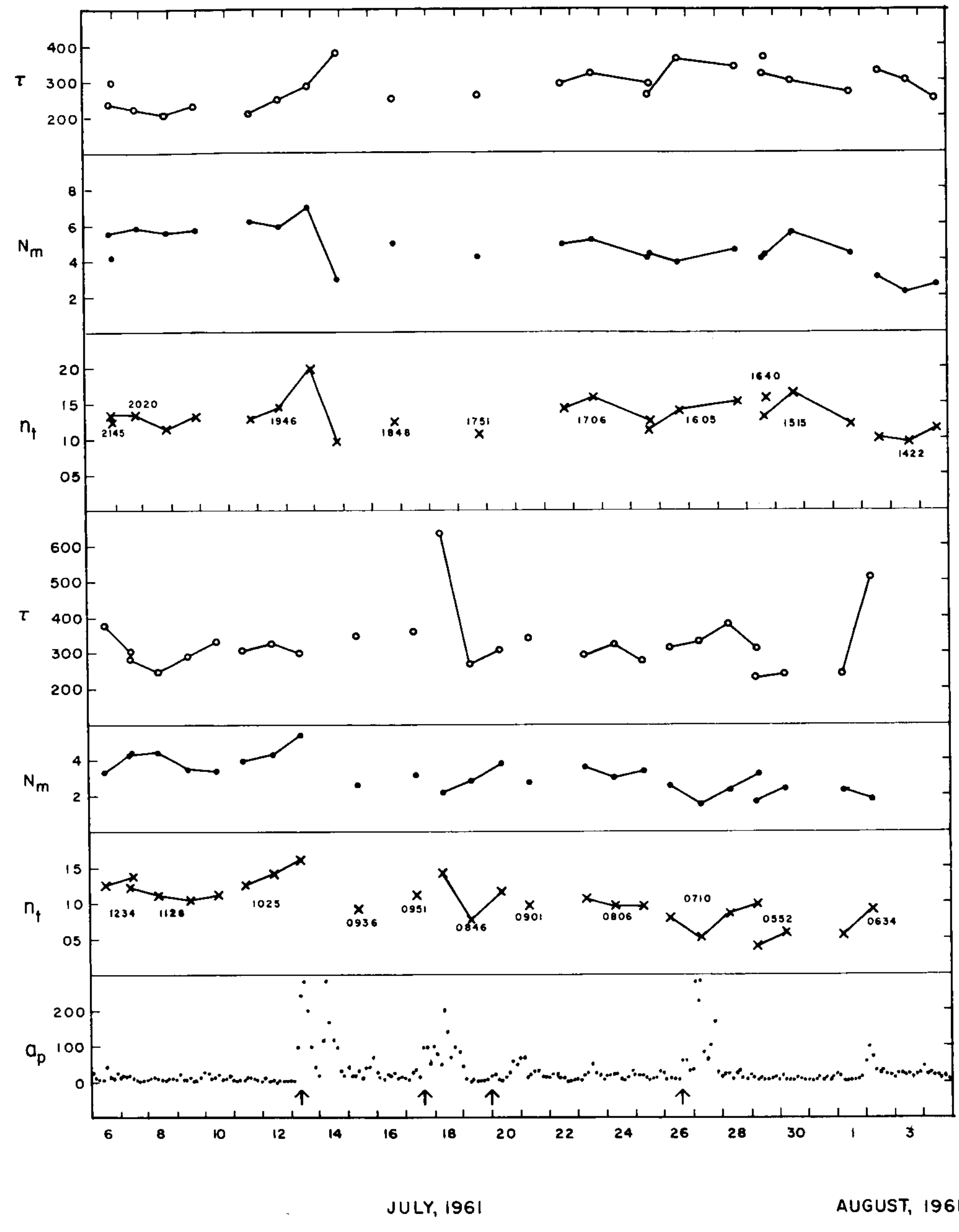


FIGURE 12

DIURNAL VARIATION OF THE RATIO $\frac{n_a}{n_b}$ FOR EQUINOX MONTHS several difficulties should be mentioned. First, with the usual Doppler techniques it is often impossible to measure the electron content in a magnetic storm because of major short-duration phase variations in the signal which obscure the Doppler pattern. These presumably arise from enhanced irregularities in ionization associated with the magnetic disturbance. As a consequence, results for many storms are not available. Again, because only two measurements of electron content can usually be made per day, it is not possible to follow the disturbances effects throughout a day. Further, the ionosphere fluctuates from day to day even under magnetically quiet conditions and it is often difficult to decide whether a change occurring during a storm is in fact related to the storm. Because there are insufficient data for averaging to be useful, the procedure adopted here is to follow day by day, at approximately the same hour, the values of the ionospheric parameters over a period including a magnetic disturbance, and to compare the storm days with those immediately preceding or following.

Figures 13 to 18 show some values of total content n_T, maximum electron density N_m and equivalent thickness τ, together with the 3-hourly planetary magnetic index A_p, on sequences of days including magnetic disturbances. The arrows indicate sudden commencements. The time of day of successive observations becomes earlier on the average. To assist in separating the diurnal effect, points for approximately the same time of day are joined by straight lines. The time is shown near the n_T points. In some of the diagrams.increasing or decreasing trends occur which are



VARIATION OF IONOSPHERIC PARAMETERS THROUGH MAGNETIC STORMS, JULY 1961

FIGURE 13

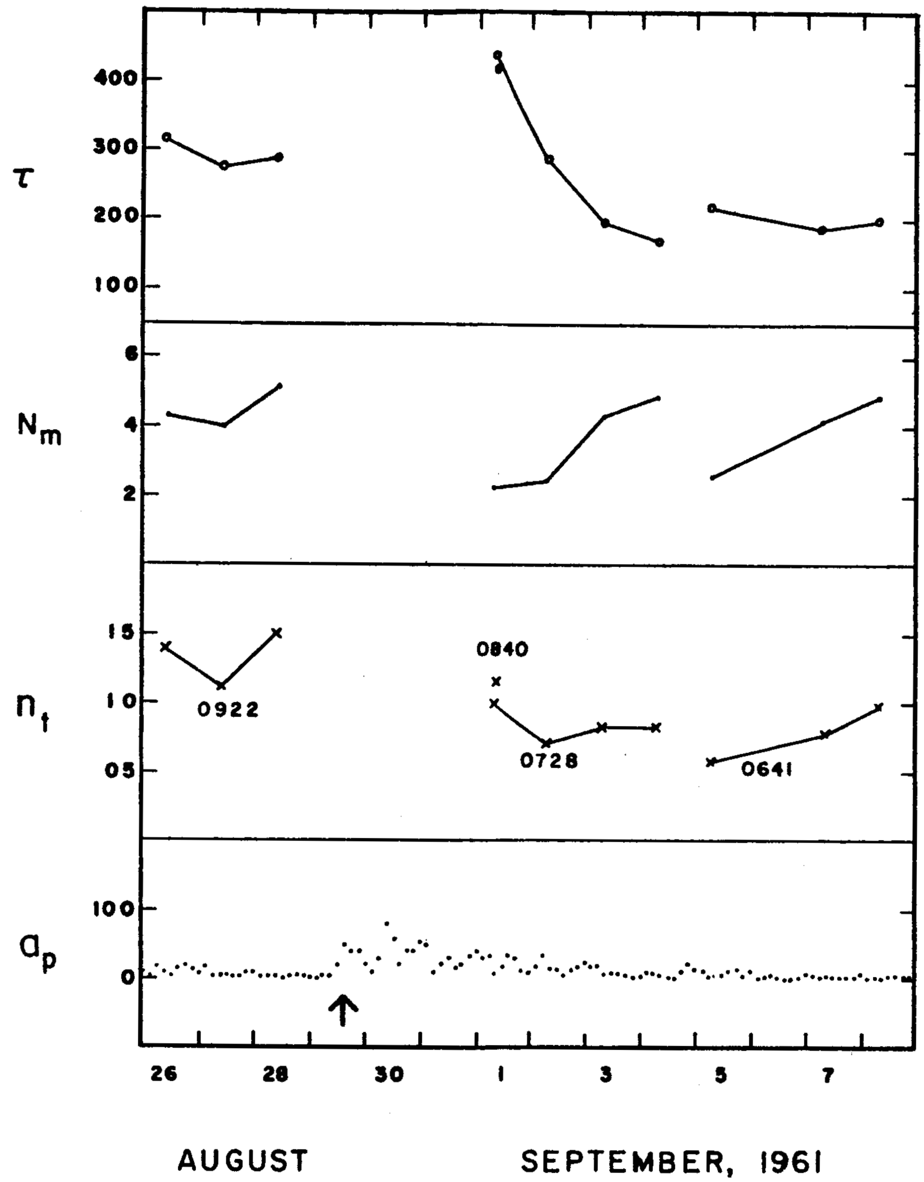


FIGURE 14

VARIATION OF IONOSPHERIC PARAMETERS THROUGH MAGNETIC STORMS, AUGUST & SEPTEMBER 1961

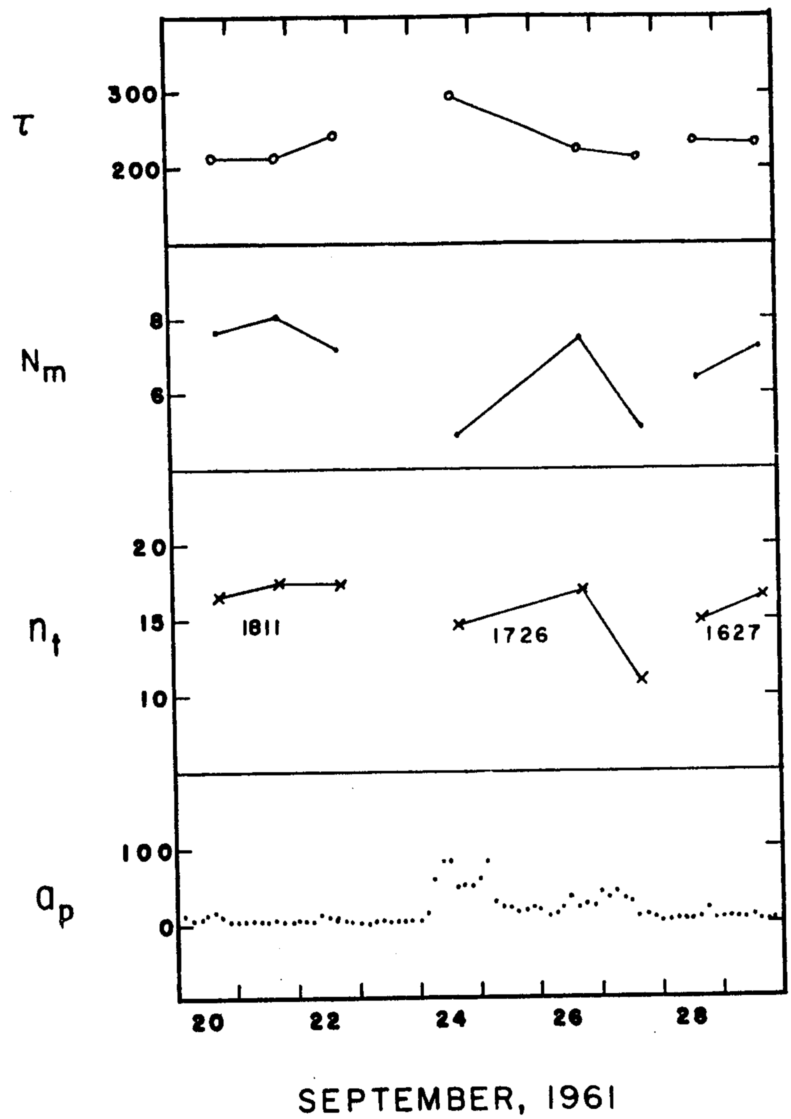
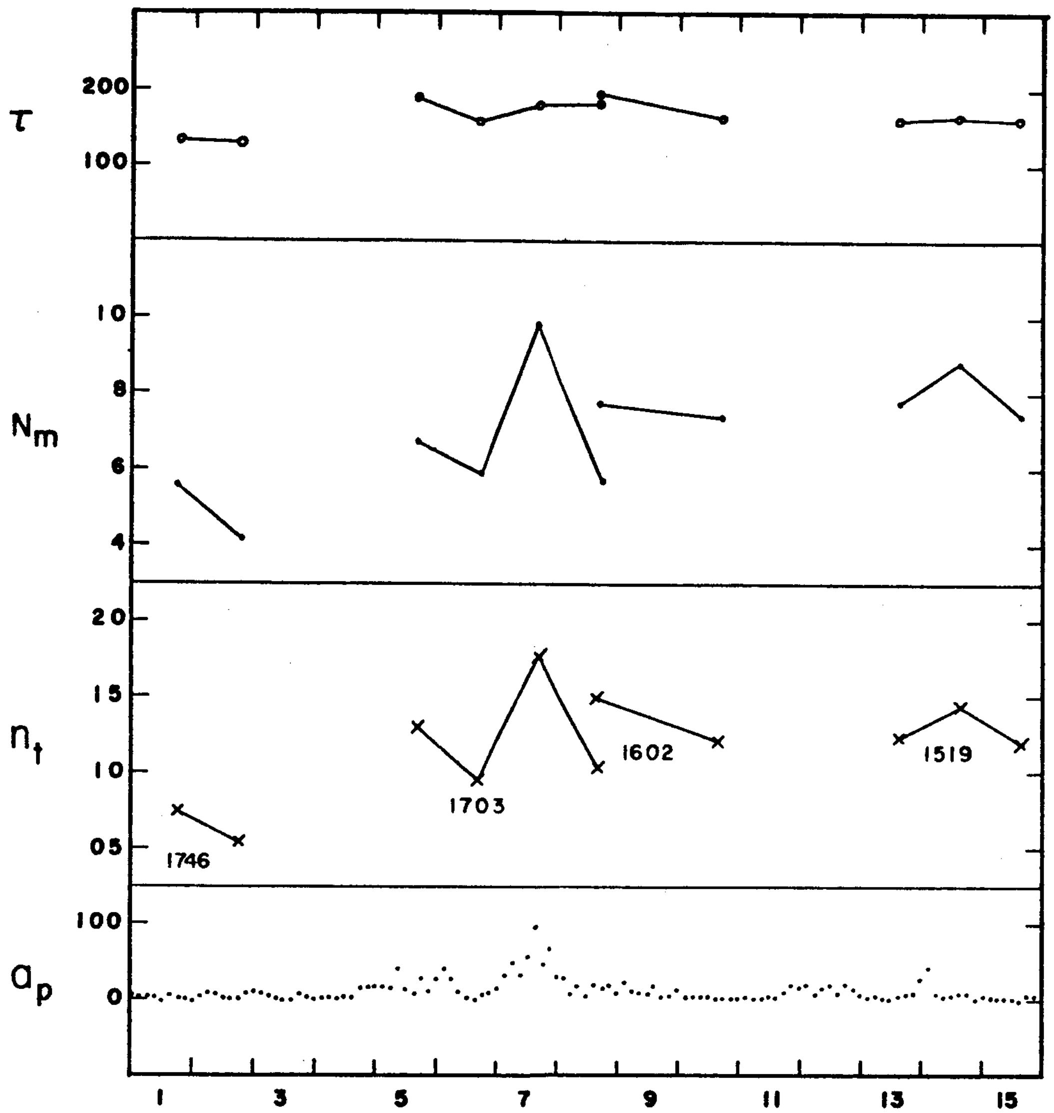


FIGURE 15

VARIATON OF IONOSPHERIC PARAMETERS THROUGH MAGNETIC STORMS, SEPTEMBER 1961



NOVEMBER, 1961

FIGURE 16

VARIATION OF IONOSPHERIC PARAMETERS THROUGH MAGNETIC STORMS, NOVEMBER 1961

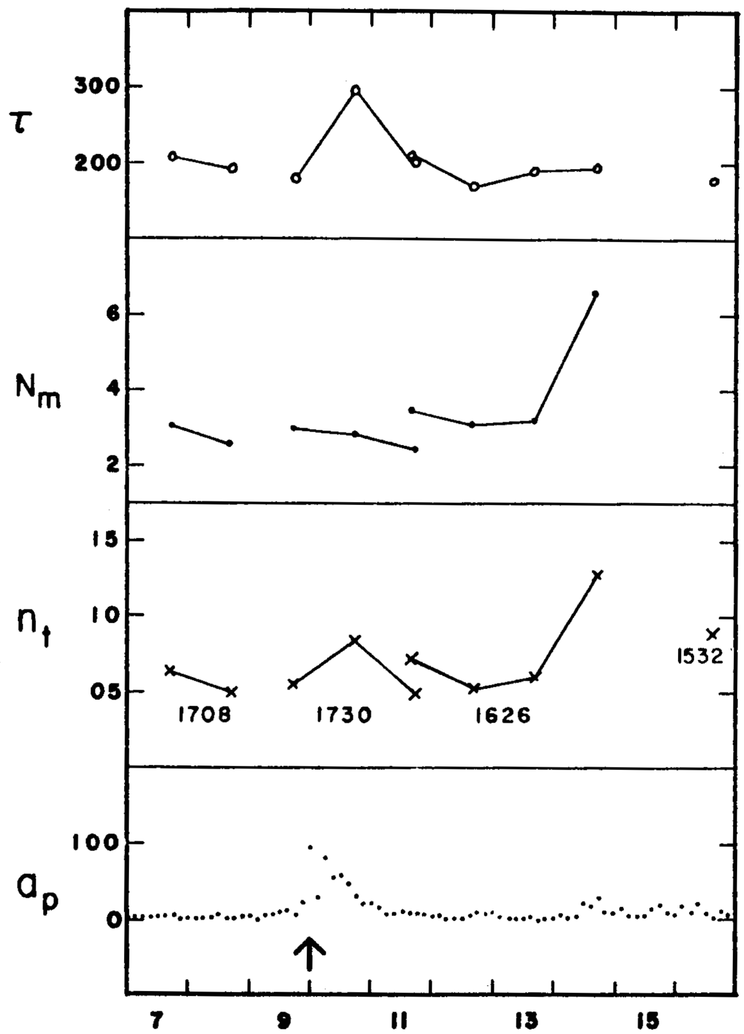


FIGURE 17

VARIATION OF IONOSPHERIC PARAMETERS THROUGH MAGNETIC STORMS, JANUARY 1962

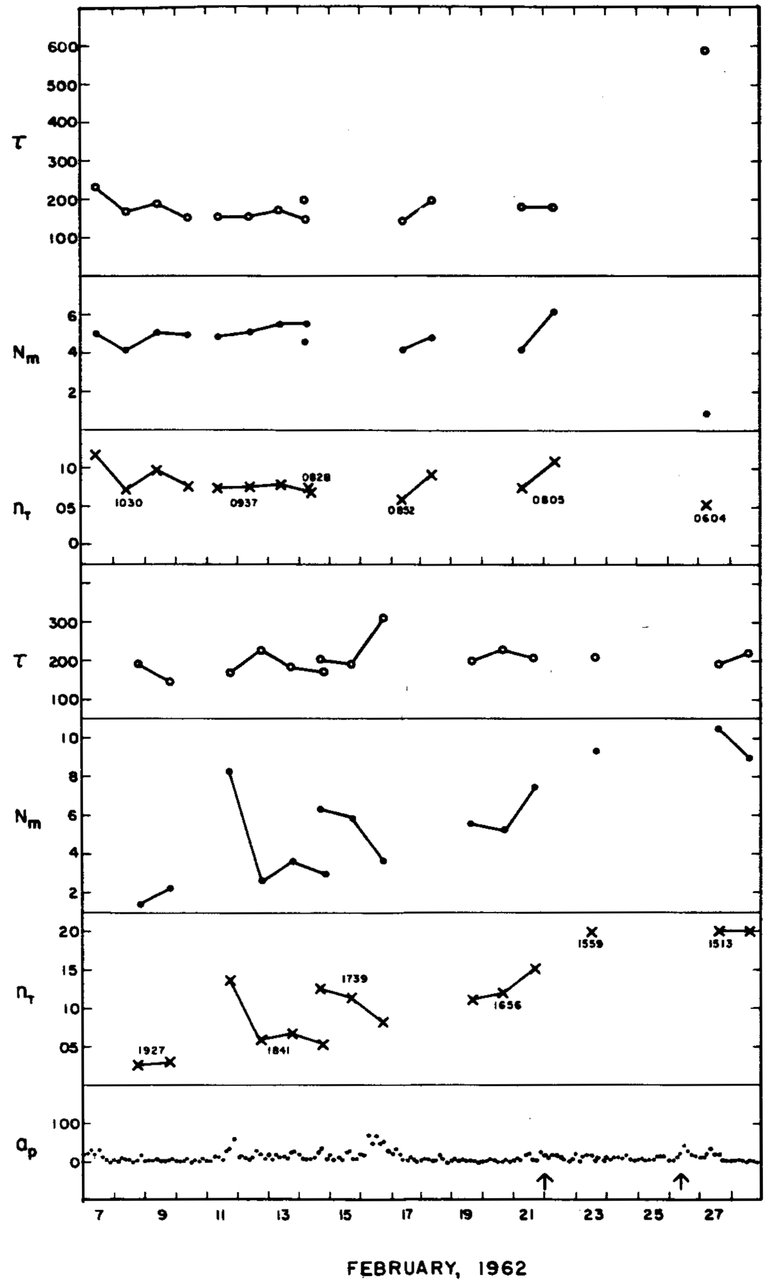


FIGURE 18
VARIATION OF IONOSPHERIC PARAMETERS
THROUGH MAGNETIC STORMS, FEB. 1962

associated with changes in solar flux. Except during storms, it may be noted that the day-to-day changes in n_T and N_m are usually similar to each other.

In Figures 13 to 18 all major increases in equivalent thickness are seen to be associated with a magnetic disturbance. Conversely, almost all disturbances are associated with an increase in thickness. Of those ionospheric variations that can be unequivocally associated with a disturbance, there are two instances of a definite increase in n_T and two instances of a definite decrease in N_m. No decrease in n_T or increases in N_m can definitely be associated with magnetic disturbances, although some small changes may have occurred. It is probable that the magnitude of the observed ionospheric changes depend on the time of observation after the commencement of the storm and the time of day when the storm commenced.

The scale heights H and H_a during disturbances, for the whole ionosphere and for the upper part respectively, have been deduced using equations (5) and (6), assuming a Chapman distribution and equality of neutral, ion and electron temperatures. The corresponding temperatures T and T_a were obtained from

$$H = \frac{kT}{mg} \quad \text{and} \quad H_a = \frac{kT_a}{mg}$$

The temperature T deduced from the total equivalent thickness τ has been calculated primarily because for several events data are not yet available to compute T_a. The temperature increase ΔT_a was obtained by subtracting from T_a the mean temperature for the appropriate month as given in Table 1. The values of ΔT and ΔT_a found for a number of disturbances are listed in Table 2, together with the maximum value of the magnetic index A_p.

In order to compare the temperature increases found in the present study with values deduced from increases in the atmospheric drag on satellites, the quantity $\Delta T_a / \Delta A_p$ has been evaluated. For this purpose the increase ΔA_p in a disturbance has been taken as equal to the maximum value of A_p in the disturbance, since A_p is relatively small under quiet conditions. Excluding the extreme values of 0 and 55 in Table 2, the mean value of $\Delta T_a / \Delta A_p$ is 7. In examining the data in Table 2 it should be remembered that, although ΔA_p is the maximum value in the disturbance, ΔT_a is not necessarily measured near the time of occurrence of the maximum and so may be considerably less than the maximum increase in temperature.

It is seen from Table 2 that the temperature increase ΔT calculated for the whole of the ionosphere is generally less than ΔT_a for the upper part of the ionosphere. In agreement with this, it is found that the ratio n_b / N_m, which is a measure of the scale height below h_m, changes by a much smaller factor in a disturbance than does the scale height above h_m. Similarly, the quantity SCAT, equal to 1/2 the semi-thickness of the parabola that best fits the N(h) profile at and just below h_m, also does not change as much as the scale height above h_m. These observations correspond to the increase in the ratio n_a / n_b in magnetic disturbances, shown by the circled points in Figures 10 and 11. During a disturbance the whole ionosphere expands vertically and the ionization distributes itself so that more of

TABLE 2

	ΔA_p	ΔT	ΔT_a	$\Delta T_a/\Delta A_p$
1961				
July 14, 1946 hrs.	280	420	450	1.6
July 18, 0846	200	1350	2200	11
July 27, 1605	280	~ 0	300	1.1
July 28, 0710	280	350	300	1.1
Aug. 2, 0634	96	850	-	9*
Sept. 1, 0800	57	550	-	10*
Sept. 24, 1726	80	300	-	4*
Nov. 7, 1703	100	~ 0	-	0*
1962				
Jan. 10, 1730	80	390	664	8
Feb. 7, 1030	33	250	310	9
Feb. 12, 1841	57	250	470	8
Feb. 16, 1739	67	420	650	10
Feb. 27, 0604	40	1500	2200	55

*$\Delta T/\Delta A_p$

the ionization lies above h_m. At the same time it is observed that h_m increases by the order of 50 km.

An increase in atmospheric temperature in magnetic storms has been observed by Jacchia and Slowey[12], in a study of the atmospheric drag on the satellite Explorer IX. This satellite had an orbital inclination of 38.8 degrees and a perigee height of about 600 km. Jacchia and Slowey found that the temperature increase ΔT was proportional to ΔA_p and that $\Delta T/\Delta A_p = 1.0$. This result includes storms when the perigee was near the high latitude limit of 38 degrees. More recently the same workers[13] have made similar measurements on the satellite Injun III, which had an inclination of 70.4 degrees and a mean perigee height of 250 km. When the perigee was in low latitudes, they again found $\Delta T/\Delta A_p \sim 1$. However, two storms occurred when the perigee was in auroral latitudes and for these $\Delta T/\Delta A_p \sim 5$. The satellite drag measurements clearly yield the temperature of the greatly predominant neutral particles rather than the ion or electron temperature.

The present results are for a middle latitude and the value $\Delta T_a/\Delta A_p \sim 7$ is considerably greater than the value 1 for lower latitudes and even the value 5 for auroral latitudes. Since the temperatures T_a are based on ionization measurements, it appears that the temperature of the charged particles, and particularly that of the electrons, is increased more than that of the neutral particles during magnetic disturbances.

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